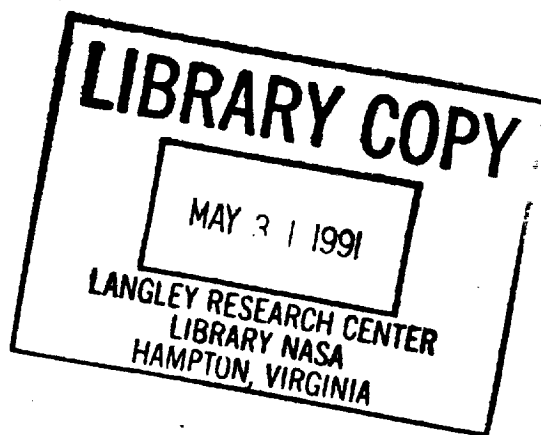# AN EVALUATION OF THE HIGH ANGLE OF ATTACK

CONCEPTUAL DESIGN MODIFICATION FOR THE

NATIONAL TRANSONIC FACILITY

PREPARED FOR

SVERDRUP & PARCEL AND ASSOCIATES, INC.

800 NORTH 12TH BOULEVARD

ST. LOUIS, MISSOURI   63101
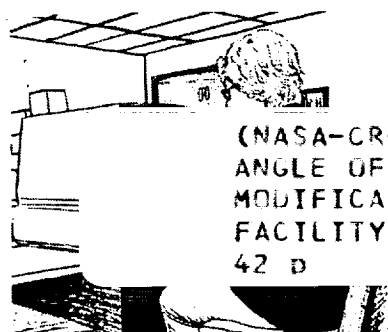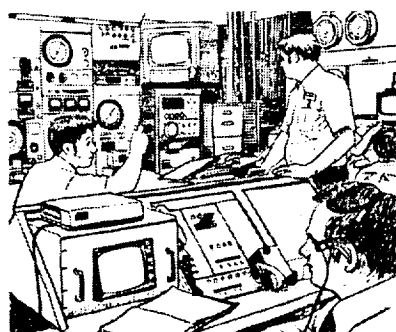
DECEMBER 1976

Sverdrup

Tullahoma
Tennessee 37388

AN EVALUATION OF THE HIGH ANGLE OF ATTACK

CONCEPTUAL DESIGN MODIFICATION FOR THE

NATIONAL TRANSONIC FACILITY

Prepared By

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December 1976

INTRODUCTION

(V-1)*

A brief study has been made to review two conceptual design modifications to the National Transonic Facility (NTF) that would provide for higher angle of attack testing than the $\pm 12^{\circ}$ capability of the present baseline design.

Modifications to the baseline design to provide the added capability affect the plenum shell and strut cover domes, the support sector and aft fairing, sector actuator and controls, support section walls including additions of flaps along the sector, sector well, centerline reentry flap and reentry flap actuation system, and addition or relocation of supporting structure in the area under the support and test section walls. Some additional pit area is also required beneath the plenum shell to provide space for the increased size of the sector cover dome and actuator.

Details of the study are presented in this report, including the scope of the task, modification information utilized, approach taken, and results and conclusions.

SCOPE

(V-2)

There are two high angle modifications currently under consideration for the NTF. One modification provides for a -11 to 30° pitch capability, and the other provides for a -11 to 19° pitch capability. The scope of this study was to review these two conceptual design modifications for a) feasibility of modified design, b) modification cost, c) payback of added pitch capability, and d) other considerations such as possible improvement areas.

Primary emphasis was placed on determining the modification cost and payback. However, the design modifications were reviewed for engineering adequacy, and a brief assessment of the complete support system design was made.

Considerations of modification cost effects on operation and maintenance, schedule impact, contingency costs, and price escalation were not included in the task. Consequently, all incremental costs are

*Indicates viewgraph associated with discussion.

in current prices and pertain only to the modification costs and potential cost benefits of the added capability.

MODIFICATION INFORMATION

(V-3)

Information associated with the design modifications that were necessary to make the desired assessments was obtained through the Langley Research Center (LaRC). Conceptual design drawings and other associated information were obtained from NTF/PO personnel during a visit to LaRC for that purpose on November 8 and 9, 1976 and additional personal discussions were held at LaRC on November 30, 1976. A list of information sources utilized to define the modifications and status of existing cost and pay-back estimates are included in Appendix A. In addition to those items listed, numerous telephone conversations were held with NTF/PO personnel during the study to clarify particular design items.

EVALUATION APPROACH

(V-4)

The general approach taken during the study was to a) review the proposed modifications for design and operational feasibility, b) estimate the cost for the -11 to 30° and -11 to 19° concepts, c) estimate the payback for each of the two concepts, and d) briefly review the complete support system for potential areas of improvement. Time limitations prevented an indepth analyses of a) and d); however, it is felt that the review was sufficient to identify any significant problem areas.

Although information was made available on existing cost estimates made by Fluidyne and LaRC, that information was not utilized as a basis for the cost estimates made during this study, except for some excavation, controls system, and insulation considerations. Likewise, information furnished by LaRC pertaining to the payback analysis was utilized only to ensure that consistent test scenarios and energy rates were utilized in the analysis.

FEASIBILITY OF DESIGN

(V-5)

The design feasibility study made during this evaluation was sufficient to identify serious design or operational problem areas, but

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time limitations did not permit detailed analyses nor suggestions for improvement. It is recognized that the conceptual designs reviewed are preliminary, and could represent less than optimum design approaches.

The engineering designs defined appear to be reasonable, however, some difficult design problems and possible operational problem areas were identified. Actuation of the support sector for the -11 to 30° modification requires a cylinder size and stroke considerably larger than the baseline design. It appears that the hydraulic fluid flow rate required for the actuator will be about 630 gpm to provide a 4°/sec pitch rate. Ensuring cylinder stability (buckling and/or oscillation during operation) for a cylinder of this size and stroke will require special attention. It is apparent that these problems have been recognized previously but the control valves for 632 gpm hydraulic fluid flow will require special equipment that apparently does not currently exist.

Both the design and operation of the sector well gate seal appear to be complicated. Alternate methods of strut well sealing should be investigated.

When the support boom is in the high angle of attack position, it appears that physical interference between the boom and flap boattail may occur with the current boattail configuration. A closer analysis of this aspect should be made. If interference is indicated, a slight alteration in the boattail geometry could possibly alleviate the problem.

COST ESTIMATES

(V-6)

Modification cost estimates were made based on the information mentioned previously. Estimating procedures used included consideration of costs associated with engineering, material, fabrication, machining, and installation. The cost breakdown was made consistent with the detail of the modification information available. It should be noted that the estimates were made with the following assumptions regarding the tunnel shell and test section.

3

1. The plenum shell is cylindrical with a 28-ft diameter, and all shell material is nine-percent nickel steel.

2. Two 14-ft diameter penetrations (one each top and bottom) with spherical caps are desired in the plenum shell for the -11 to 30° modification, even though a 10-ft penetration should suffice for the top configuration.

3. The top and bottom wall configuration change from six to five slots, as a result of high angle of attack considerations, is considered to have negligible effect on the modification costs (per LaRC discussions).

4. Relocations of the reentry flap actuating systems, and provision of additional linkages, are considered as a modification cost.

Modifications associated with the design changes that have the major impact on costs are:

1. Enlargement of pit under plenum for sector dome and cylinder.

2. Plenum shell penetrations and domes, along with associated insulation.

3. Increased support sector arc length.

4. Increased sector actuator cylinder size and stroke.

5. Alteration of support frames under test section and model support section.

6. Relocation of actuators, and provisions for additional linkages for reentry flaps, including added actuator and all associated linkages to provide for the centerline flap pivot point translation.

7. Flaps and actuators along sector on bottom support section wall.

8. Addition of supporting structure below support section wall.

9. Increased size of strut well and associated seals.

In general, the above modifications are much more extensive for the -11 to 30° system, and some are not applicable to the -11 to 19° modification.

Each of the two design modifications was assessed, and a total cost differential relative to the baseline design was derived. The approach used was to estimate the cost of all services based on Middle Tennessee rates, and then apply a multiplication factor of 2.85. This factor accounts for profit, overhead costs, and Davis-Bacon pay differentials. Through experience with similar type work, this factor has proven to be a fairly reliable one.

In presenting the cost estimates, an attempt has been made to separate the incremental costs for each modification into the respective work packages (WP) associated with the work effort. Work packages identified to be influenced by the modifications are:

WP 1. Tunnel foundations

      3. Tunnel structures (shell)

      4. Tunnel components

      5. Installation

      6. Insulation and liner system

    12. Model support system

    13. Process controls

A breakdown of the cost estimates for each system is included in Appendix B. (V-7)

A summary of the cost results shows that the total cost increment (relative to the baseline) for the -11 to 30° modification is $953,800. With regard to the shell modification cost (WP-3), what was considered to be accurate information on costs for a forged collar penetration reinforcement was not available during the study, and the estimated cost for the reinforcement was based on a rolled and welded shell plate. An inquiry was made to U. S. Steel regarding the forged collar, but no information has been received. If a forged collar is an absolute requirement, additional cost differential will result.

The summary for the -11 to 19° modification shows that the total cost increment (relative to the baseline design) for that modification is $362,920. Similar shell reinforcements were assumed for this system as those mentioned for the -11 to 30° case.

PAYBACK ANALYSIS

Assuming for this analysis that all data acquisition is for a one-degree per second continuous sweep, the payback results were determined (see Appendix C). To obtain reasonable results, the NTF productivity was normalized to 8000 "complete" polars per year. This implies that the required number of "partial" or "extra" polars must be allowed to vary proportionally to give the original mix, and the operating crew had to also be adjusted for the extra work as follows:

Configuration	High α "Extra" Polars	St. Sting "Partial" Polars	Total "All" Polars	Number Personnel Manyears
24-Degree	1846.2	8,000	9846.2	92.31
30-Degree	1142.8	8,000	9142.8	85.72
41-Degree	1000	7,000	8000	75.00

The resulting cost breakdown for the three configurations of the model support, is then as shown in V-9. Note the very small contribution of electrical energy and the overall reduction arising from the continuous sweep method of data acquisition.

The cost saving or the annual delta dollars return for the two modifications as compared to the 24-degree system is as illustrated in V-10. If we neglect the compound interest value of money and capitalization, the years for each of the candidate systems to recoup the initial investment can be readily calculated as follows:

Configuration	10^6 1976 Δ \$ Cost	10^6 1976 Δ \$ Saved	1976 Years to Payback
24-Degree	0	0	-
30-Degree	0.363	0.392	0.926
41-Degree	0.954	1.049	0.909

Of course, the scheduling impact costs and inflationary corrections
would have to be considered to get a realistic payback time period. However,
this manipulation has been defined as beyond the scope of this study.

OTHER CONSIDERATIONS

(V-11)

During the review for modification feasibility and cost estimating,
it was noted that no apparent provision has been made for a sector brake
system. It is recognized that blocking valves can be used to prevent sector
movement in the event of hydraulic system failure, that the system can be
pinned in position during model and sting work, and that cushioned stops
will most likely prevent damage to the support sector in the event of
actuator failure. However, the result of an actuator failure during test-
ing might be catastrophic from the standpoint of sting and model safety.
That is, would the model and/or sting likely fail (when the sector impacts
the stops) and allow components to go down the tunnel and jeopardize the
compressor? It is recommended that these aspects be addressed and that
some method be considered to control the sector acceleration in the event
of actuator failure.

CONCLUSIONS

(V-12)

Based on this brief analysis, the following conclusions have been
reached.

1. Design approaches for the two potential modifications
   to provide for higher angles of attack appear feasible.

2. Some difficult design and operational areas should be
   studied in more detail. In particular, the sector actuator
   and controls should be studied further.

3. The incremental cost from the baseline to provide a -11
   to 30° pitch capability is approximately $954,000 in
   current prices.

4. The incremental cost from the baseline to provide a
   -11 to 19° pitch capability is approximately $363,000.

5. Cost savings per complete polar are $131.20/polar for the
   -11 to 30° system, and $49.10 for the -11 to 19° system.

6. Annual estimated savings based on an 8000 complete polar
   year are $1.05 million for the -11 to 30° system and
   $0.39 million for the -11 to 19° system.

7. It is recommended that provisions for a support sector
   brake be considered.

7

TASK

EVALUATION OF THE NTF HIGH ANGLE OF ATTACK

CONCEPTUAL DESIGN MODIFICATIONS

BY

SVERDRUP & PARCEL AND ASSOCIATES, INC.

ST. LOUIS, MISSOURI

V-1

T A S K   S C O P E

● REVIEW CONCEPTUAL DESIGN MODIFICATIONS ASSOCIATED WITH A -11 TO 30° AND A -11 TO 19° MODEL SUPPORT SYSTEM FOR THE NTF.

● FEASIBILITY OF MODIFIED DESIGN

● MODIFICATION COST

● PAYBACK OF ADDED PITCH CAPABILITY

● OTHER CONSIDERATIONS - POTENTIAL IMPROVEMENTS

V-2

9

M O D I F I C A T I O N   I N F O R M A T I O N

● INFORMATION FURNISHED BY OR THROUGH LANGLEY RESEARCH CENTER, NTF/PO

  ● DRAWINGS OF DESIGN CONCEPTS

      BASELINE CONFIGURATION, $\pm$ 12^0

      30^0 MODIFICATION, -11 TO 30^0

      19^0 MODIFICATION, -11 TO 19^0

  ● ASSOCIATED REPORTS AND MEMORANDA

  ● PERSONAL DISCUSSIONS WITH NTF/PO PERSONNEL

V-3

10

EVALUATION APPROACH

- REVIEW OF MODIFICATIONS FOR DESIGN AND OPERATIONAL FEASIBILITY.

- ESTIMATE OF MODIFICATION COSTS FOR EACH INCREASED ANGLE CONCEPT.

- ESTIMATE OF PAYBACK FOR EACH INCREASED ANGLE CONCEPT.

- CONSIDERATION OF POTENTIAL DESIGN IMPROVEMENTS.

V-4

11

FEASIBILITY OF DESIGN

● ENGINEERING APPROACHES DEFINED APPEAR REASONABLE.

● DIFFICULT DESIGN AND/OR OPERATIONAL PROBLEM AREAS.

  ● SECTOR ACTUATION AND CONTROL

  ● GATE SEAL ON STRUT WELL

  ● POSSIBLE BOOM-SLOT BOATTAIL INTERFERENCE

V-5

12

COST ESTIMATING CONSIDERATIONS

● PLENUM SHELL IS 28-FT INSIDE DIAMETER CYLINDER – SHELL MATERIAL 9% NICKEL STEEL

● CHANGE IN WALL SLOT CONFIGURATION FROM SIX TO FIVE WILL HAVE NEGLIGIBLE COST IMPACT ON TEST SECTION WALL AND SUPPORTS

● REORIENTATION OF REENTRY FLAP ACTUATING SYSTEM FOR THE -11 TO 30° MODIFICATION IS CONSIDERED AS MODIFICATION COST

● TWO 14-FT DIAMETER PENETRATIONS (ONE TOP AND BOTTOM) WITH SPHERICAL CAPS ARE DESIRED.

● COST ESTIMATES INCLUDE ENGINEERING, MATERIAL, FABRICATION, MACHINING, AND INSTALLATION WITH ALLOWANCES FOR PROFIT, OVERHEAD, AND DAVIS-BACON PAY DIFFERENTIALS

V-6

△COST ESTIMATE: -11 TO 30° MODIFICATION

WORK PACKAGE	△ $ *
1	19,000
3	348,300
4	296,500
5	15,000
6	25,000
12	144,000
13	106,000
TOTAL	$953,800

* BASED ON CURRENT PRICES

V-7

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Δ COST ESTIMATE: -11 TO 19° MODIFICATION

WORK PACKAGE	Δ $ *
3	115,280
4	76,500
5	10,000
12	123,140
13	38,000
TOTAL	$362,920

* BASED ON CURRENT PRICES

V-8
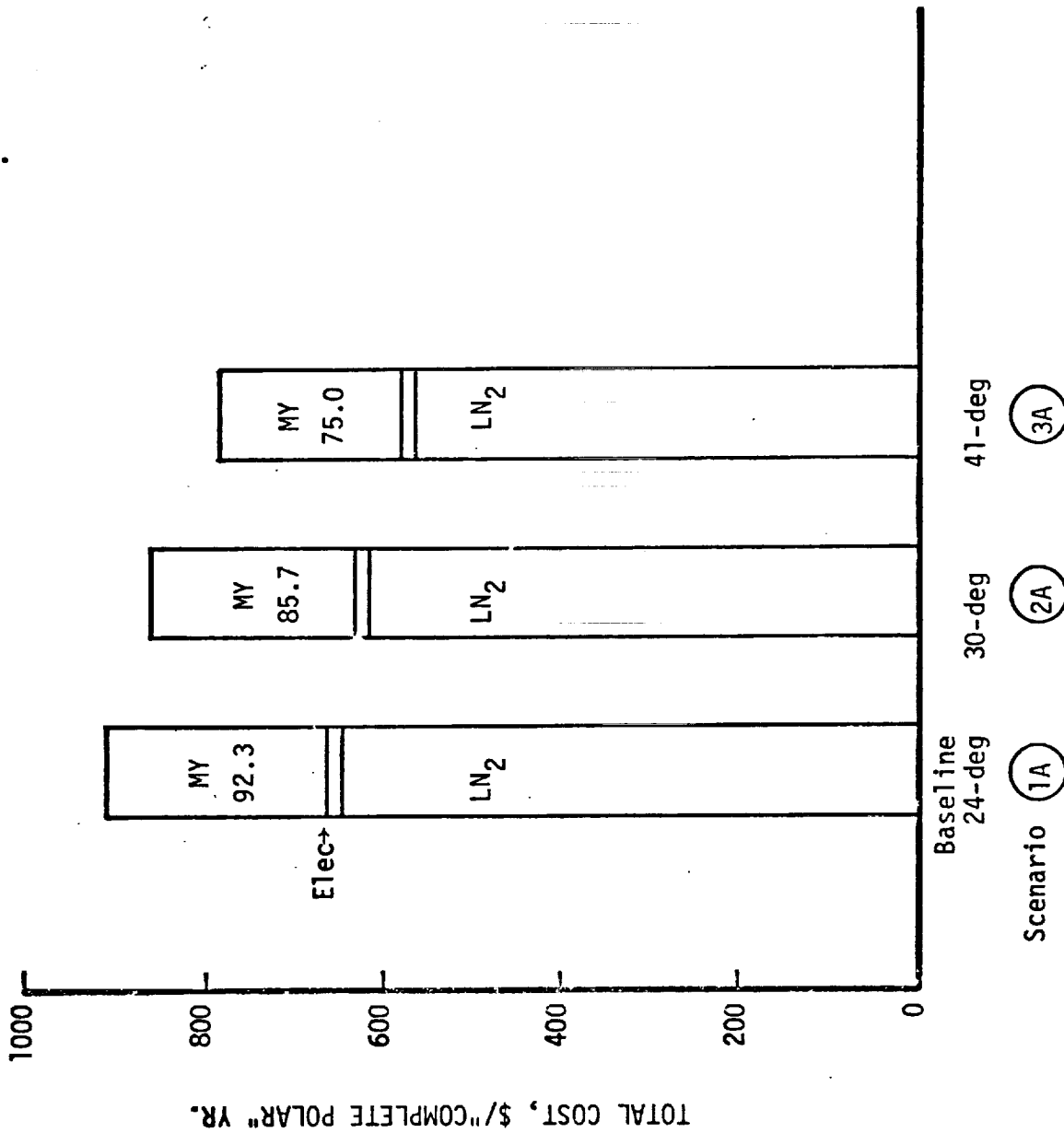
15

TOTAL COST, $/"COMPLETE POLAR" YR.

1000

800

600

400

200

0

Elec→

MY
92.3

LN$_2$

MY
85.7

LN$_2$

MY
75.0

LN$_2$

Baseline
24-deg

30-deg

41-deg

Scenario ①A ②A ③A

"COMPLETE POLAR" COST BREAKDOWN FOR ONE-DEGREE PER SECOND
CONTINUOUS SWEEP AND 8000 "COMPLETE POLARS"/YR.

V-9
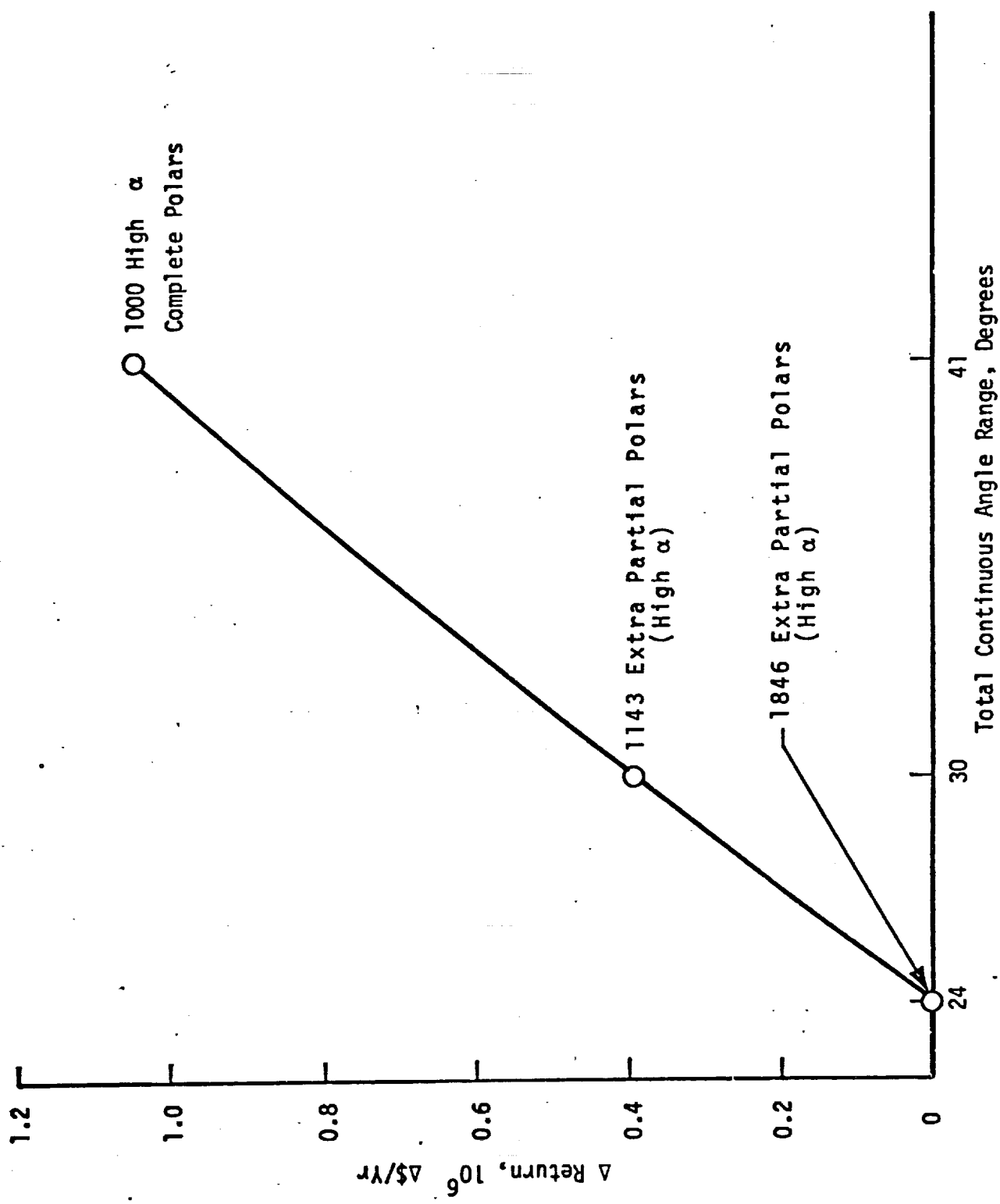
V-10   Projected Annual Operating Cost Return Compared to the
        24-Deg System for 8000 "Complete Polars"/Year

OTHER CONSIDERATIONS

● Sector Brake System – To Control Sector Acceleration

In Event of Actuator Failure

V-11

CONCLUSIONS

- **Design Approach Appears Feasible**

- **Some Difficult Design Areas Require Additional Study**

- **Δ Cost From Baseline to Provide -11 to 30° Pitch System = $954,000**

- **Δ Cost From Baseline to Provide -11 to 19° Pitch System = $363,000**

- **Cost Saving Per Complete Polar:** -11 to 30° System = $131.20

   -11 to 19° System = $ 49.10

- **Savings per 8000 Complete Polar Year: -11 to 30° System = $1.049 million**

   -11 to 19° System = $0.392 million

- **Recommend Brake System for Sector be Considered**

V-12

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APPENDIX A

DESIGN MODIFICATION INFORMATION SOURCES

Sources of information used to define the modifications for the two systems evaluated are listed below:

1. Fluidyne Drawings, $\pm$ 12° Baseline: SK1060-719, SK1060-720, SK1060-7233, 7241, 7246, 7248, 7258, 7259, 7260, 7261.

2. Fluidyne Drawings, -11 to 30-deg: SK1060-7271, 7272, SK1060-7273, 7274, 7275, 7276, 7277, 7278, 7279, 7280, 7281, SK1060-7282, 7283, 7284, 7286.

3. Conceptual layouts by LaRC: -11 to 30° and -11 to 19° systems. Five sheets - no drawing numbers.

4. Information sheet on insulation material.

5. Letter of Agreement - High Angle-of-Attack System Modifications, Langley-Fluidyne, 20 Oct. 1976.

6. Memorandum Report of a High Angle of Attack Model Support System for the NTF, Fluidyne Engineering, September 1976 (includes cost estimates for the -11 to 30-deg Mod.).

7. Aerodynamic Lines, Loads and Performance for the National Transonic Facility, compiled by Transonic Requirements Group, December 1975.

8. LaRC Cost Estimates for the -11 to 30-deg System.

9. LaRC Cost Estimates for the -11 to 19-deg System.

10. Payback Information and Analysis Approach used by LaRC.

11. Personal discussions with LaRC NTF/PO personnel.

APPENDIX B

COST BREAKDOWN FOR INCREASED ANGLE MODIFICATIONS

Cost estimates for the conceptual design modifications showing engineering, shop (fab and machine), installation, and material estimates are given in Table B-1 for the -11 to 30° modification, and in Table B-2 for the -11 to 19° modification. The estimates are separated into work packages with appropriate comments for each work package. Manhour dollar estimates shown represent Middle Tennessee rates multiplied by a factor of 2.85. This factor accounts for profit, overhead costs, and Davis-Bacon pay differentials. Experience with cost estimates for similar type work has shown this factor to be a reliable one.

TABLE B-1

Cost Estimates for the -11 to 30° Modification

WP-1 (Tunnel foundations)

Remove Soil $\quad \dfrac{(10)(29)(17)+(50)(29)(3)}{27}$ = 344 yards @ $5.00 = $ 1,720

Additional $\quad \dfrac{(10)(20)(2)(2)+(29)(3)(2)(2)+(40)(3)(2)(2)+(10)(29)(2.5)}{27}$ =
Concrete

$\qquad\qquad\qquad\qquad\qquad\qquad$ = 87 yards @ $150 $\quad$ = $\quad$ 13,050

Additional Sump Pumps, Piping, Etc. $\qquad\qquad\qquad\qquad\qquad\qquad$ 4,230

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ $19,000

Comments: Estimate is based on extending pit for the baseline configuration
10-ft in length and 3-ft in depth, making size 50-ft x 29-ft
x 20-ft deep.

Clearance between the sector actuator cylinder and the wall of
a utility tunnel appears to be marginal. If relocation of the
utility tunnel is necessary, additional costs will result.

WP-3 (Shell modification)

	Engr.	Shop	Install.	Material	Total
(Manhours)	800	2,500	5,800		
(Dollars)	$22,800	$49,800	115,700	160,000	$348,300

Comments: Penetrations in tunnel shell must be reinforced at shell open-
ings. This can be accomplished by heavy forged collars or by
welding a formed plate collar around the junction of the two
cylinders. This estimate is based on the formed and welded
type of construction because reliable costs for heavy forgings
were not available. Costs are delta costs based on baseline
configuration, and include 14-ft penetrations on both top and
bottom with spherical shaped wells.

Table B-1   (Continued)

WP-4 (Tunnel components)

	Engr.	Shop	Install.	Material	Total
(Manhours)	2,080	7,460	2,420		
(Dollars)	59,300	149,000	48,000	40,200	$296,500

Comments: Estimate is based on changes in the support rings and beams, model support floor bridging structure, strut flaps with actuators and controls, reentry flap modifications (linkages, translating centerline flap, added actuator and controls, and torque tubes), strut well and gate seal, and actuator mounts.

WP-5   (Installation)

	Engr.	Shop	Install.	Material	Total
(Manhours)	-	-	600	-	-
(Dollars)	-	-	12,000	$ 3,000	$15,000

Comments: Estimate represents costs of handling the added weight and size of the larger support sector during installation in the tunnel.

WP-6   (Insulation and liner system)

	Engr.	Install.	Material	Total
(Manhours)	120	300		
(Dollars)	$3,400	$6,000	$15,600	$25,000

Comments: Estimate is based on insulating 1000 square feet of area of the increased surface caused by two shell penetrations.

Table B-1 (Continued)

WP-12 (Model support system)

	Engr.	Shop	Install.	Material	Total
(Manhours)	920	1,420	800		
(Dollars)	$26,200	$28,400	$16,000	$73,400	$144,000

Comments: Estimate based on increasing length of sector to accommodate longer pitch range, longer aft fixed fairing, added strut support structure, added capability for determining strut position, increased strut actuator size, added actuator controls, and added insulation for actuator and potentiometer.

WP-13 (Process controls)

	Engr.	Shop	Install.	Material	Total
(Manhours)	400		650		
(Dollars)	11,400		$13,000	$81,600	$106,000

Comments: Estimate includes increase in hydraulic system supply piping, accumulators, etc., to handle the larger flow rates for the increased actuator cylinder demand.

TOTAL COST $953,800

TABLE B-2

Cost Estimates for the -11 to 19° Modification

WP-3 (Shell modification)

	Engr.	Shop	Install.	Material	Total
(Manhours)	400	1,100	2,600	-	-
(Dollars)	$11,400	$21,980	$51,900	$30,000	$115,280

Comments: Penetrations in tunnel shell must be reinforced at shell openings. This can be accomplished by heavy forged collars or by welding a formed plate collar around the junction of the two cylinders. This estimate is based on the formed and welded type of construction because reliable costs for heavy forgings were not available. Costs are delta costs relative to baseline configuration. Includes added top penetration and well, and changes to the bottom well.

WP-4 (Tunnel components)

	Engr.	Shop	Install.	Material	Total
(Manhours)	480	1,630	760	-	-
(Dollars)	$13,700	$32,500	$15,100	$15,200	$ 76,500

Comments: Estimate based on changes in support frames, model support floor, support floor flaps and actuators, sector well, and reentry flap actuation.

WP-5 (Installation)

	Engr.	Shop	Install.	Material	Total
(Manhours)	-	-	400	-	-
(Dollars)	-	-	$8,000	$ 2,000	$ 10,000

Comments: Estimate represents costs of handling the added weight and size of the larger support sector during installation in the tunnel.

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Table B-2 (Continued)

WP-12   (Model support system)

	Engr.	Shop	Install.	Material	Total
(Manhours)	840	1,280	530	-	-
(Dollars)	$23,940	$25,500	$10,600	$63,100	$123,140

Comments: Estimate based on increasing length of sector to accommodate longer pitch range, longer aft fixed fairing, added strut support structure, added capability for determining strut position, increased strut actuator size, added actuator controls, and added insulation for actuator and potentiometer.

WP-13   (Process controls)

	Engr.	Shop	Install.	Material	Total
(Manhours)	300		240		
(Dollars)	$8,550		$4,770	$24,680	$ 38,000

Comments: Estimate includes increase in hydraulic system supply piping, accumulators, etc., to handle the larger flow rates for the increased actuator cylinder demand.

TOTAL COST $362,920

APPENDIX C

PAYBACK ANALYSES

Continuous-Sweep Approach

As discussed in Ref. 1, the eventual data mode that should evolve
for NTF will be a continuous sweep method. There will be a few very
sensitive cruise performance tests where some pitch-pause will be done,
however, the large bulk of high angle stability assessment data will,
in our opinion, be obtained by a continuous sweep of the support strut.
We will, therefore, assume for this analysis that all data acquisition is
for a one-degree per second continuous sweep. This implies that the
automated tunnel condition control system must be designed for this
criteria even if it requires that high-response test-section drag flaps
must be provided.

The staff at LaRC has done some study of the effect of data
dwell time on LN_2 and electric power usage. Their data are shown in
Figures 1 and 2 where the continuous-sweep data from Ref. 1 are also
plotted as equivalent to zero dwell time. The correlation between the
two independent and quite different approaches is quite good considering
that the Ref. 1 analysis utilized a compressor pressure ratio curve
(λ_c Vs M) that was somewhat lower than present estimates, and the heat
leakage through the ducting insulation was neglected. Without taking
the time to rework the Ref. 1 analysis, which would require considerable
effort, a quick correction can be made to allow for the increased λ_c effect
and insulation leakage as shown in Tables 1 and 2. Note that the
estimation categories of Ref. 1 allow us to also calculate the added
usage that would result if all data were obtained over the complete
sweep range of not only the baseline 24-degree system but also the proposed
30-degree and 41-degree model supports. By this approach, we do not
have to get involved in an assessment of how many data points would be
required to define non-linear high angle coefficient effects, since
continuous-sweep data can be subdivided into as many data points as
needed as long as the data sampling rate is something reasonable, like
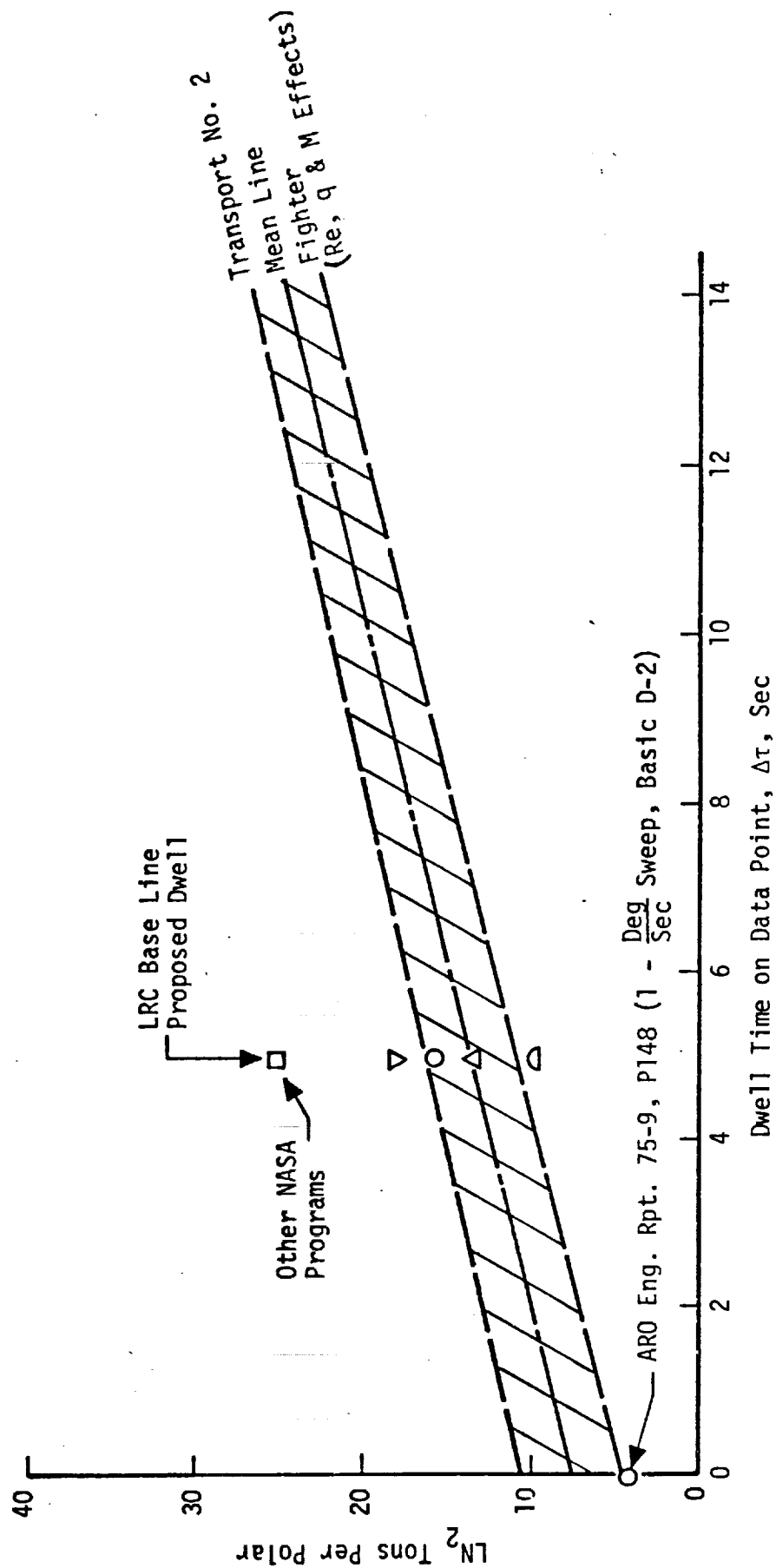500 samples per second, and modern digital filtering methods are employed.

Figure 1 - Effect of Data Dwell Time on LN_2 Consumption, Base Line Configuration ±12 Deg Strut
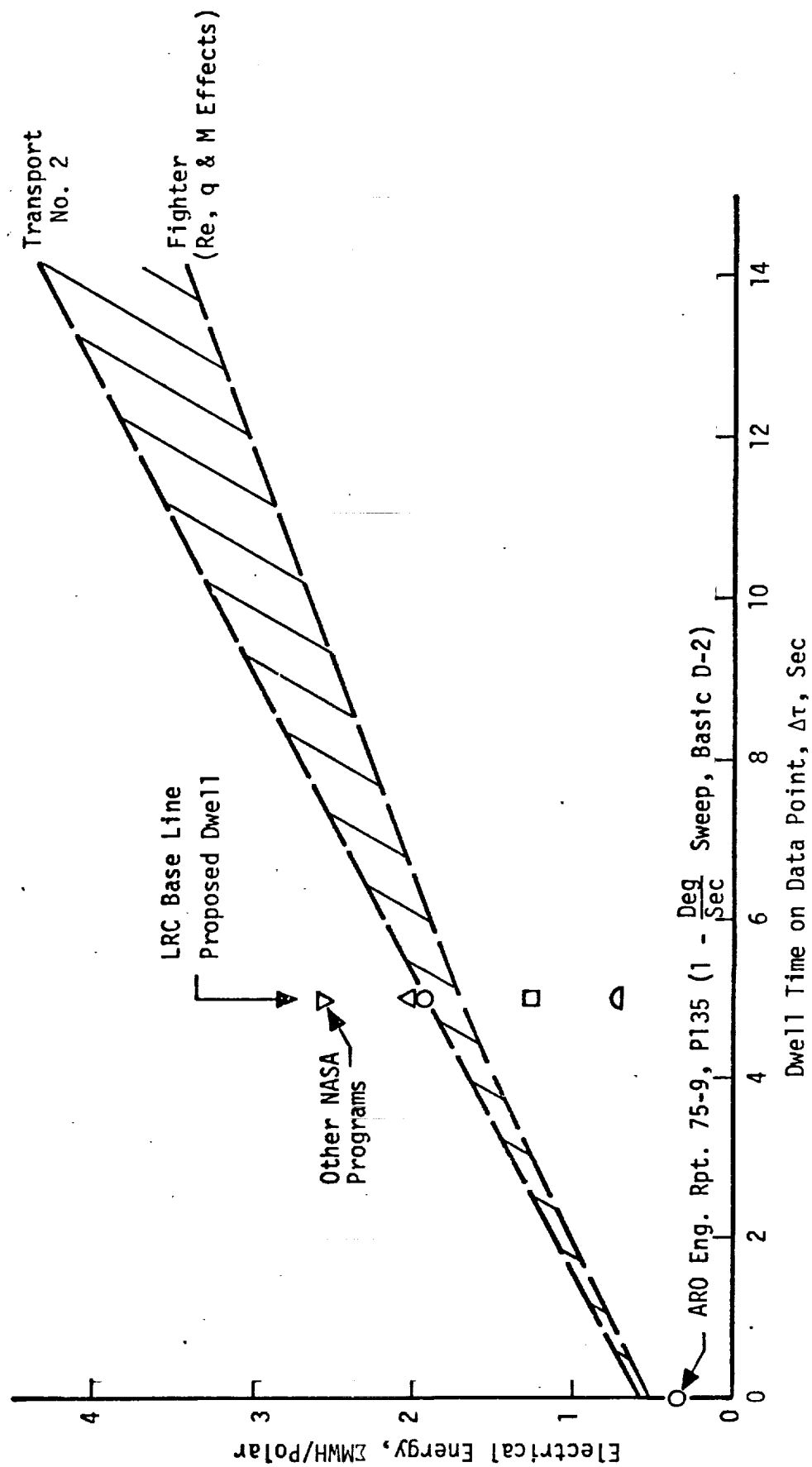
Figure 2 - Effect of Data Dwell Time on Electrical Energy Consumption, Base Line Configuration ±12 Deg Sting

TABLE 1
IMPLIED LN$_2$ CONSUMPTION FOR DIFFERENT
MODEL SUPPORT SYSTEMS IN NTF
(FOR 8000 "PARTIAL POLARS" PER YEAR & 1 DEG/SEC SWEEP RATE)

CATEGORIZATION	24-DEG TONS/YR	30-DEG TONS/YR	41-DEG TONS/YR	REMARKS
● LN$_2$ - DATA SWEEPS	23,920*	29,900	40,863	SWEEP RANGE SCALING
● LN$_2$ - MACH NO. CHANGES	3,312*	3,312	3,312	NOMINALLY CONSTANT (NEGLECTING λ_c INCREASE EFFECT)
● LN$_2$ - FILLS AND REFILLS	6,476*	6,476	6,476	NOMINALLY CONSTANT (INTERNAL MASS HELPS GASIFY)
● LN$_2$ - IMPLIED CORRECTION	26,292	32,865	44,916	INSULATION LOSSES, λ_c INCREASE AND REAL-GAS EFFECTS WITH SWEEP RANGE SCALING
● TOTAL LN$_2$, TONS/YR	60,000	72,553	95,567	ASSUMES GIVEN SWEEP RANGE AT ALL TIMES
● TOTAL LN$_2$, TONS/POLAR-YR	7.500	9.069	11.946	
● TOTAL LN$_2$, TONS/POLAR-YR-DEG	0.31250	0.30230	0.29136	

* Ref. ARO ER 75-9, p. 148, Config. D-2

TABLE 2
IMPLIED ELECTRICAL ENERGY CONSUMPTION FOR DIFFERENT
MODEL SUPPORT SYSTEMS WITH $(\eta_{Gear} (\eta_{Drive})) = (0.98)(0.80) \doteq 0.784$
(FOR 8000 "PARTIAL POLARS" PER YEAR & 1 DEG/SEC SWEEP RATE)

CATEGORIZATION	24 DEG MWH/YR	30 DEG MWH/YR	41 DEG MWH/YR	REMARKS
• METERED – DATA SWEEPS	1978.7*	2473.4	3380.3	SWEEP RANGE SCALING
• METERED – M CHANGES	274.0*	274.0	274.0	NOMINALLY CONSTANT (NEGLECTING λ_c INCREASE EFFECT)
• METERED – GASIFY LN$_2$	535.7*	535.7	535.7	NOMINALLY CONSTANT (INTERNAL MASS HELPS GASIFY)
• IMPLIED CORRECTION	1691.2	2114.0	2889.1	λ_c INCREASE AND REAL-GAS EFFECTS WITH SWEEP RANGE SCALING
• TOTAL ENERGY, MWH/YR	4479.2	5397.1	7079.1	ASSUMES GIVEN SWEEP RANGE AT ALL TIMES $\longrightarrow$
• TOTAL ENERGY, MWH/POLAR-YR	0.56000	0.67464	0.88489	
• TOTAL ENERGY, MWH/POLAR-YR-DEG	0.02333	0.022488	0.021583	

* Ref. ARO ER 75-9, p. 135, Config. D-2 (Divided by 0.784)

From the plotted information in Figures 1 and 2, it is also interesting to point out that the continuous-sweep method will require an average LN_2 consumption of about 7.5 tons/polar and 0.56 MWH/polar as compared to the 5-second dwell pitch-pause approach where 13.5 tons/polar and 1.82 MWH/polar would be required; a strong "energy-conservation" effect.

The Semantics of "Polars"

To discuss how high angle "complete polars" can be constructed by the combination of some straight-sting "partial polars" and some bent-sting "extra partial polars," some polar semantics are introduced. A brief definition of a "complete polar" is what the aerodynamicists wants; it may only be ± 12 degree data, zero to 41-degree data, or something in between. Depending on the support strut capabilities, a "complete polar" may or may not require extra bent-sting "partial" or "extra" polars.

Operational Scenarios

To assess the operational usefulness of the baseline system compared to the two proposed high angle systems, the scenarios of LaRC were utilized, since the definition of something like that is beyond the scope of this analysis. We have, however, listed our interpretation of these "ground rules" as shown in Table 3. Note that the "complete polar" productivity for the three scenarios varies from 6500 to 8000; a consequence of "polar" semantics that will have to be corrected or normalized to make a fair payback comparison.

NTF Operating Personnel

If it is postulated that NTF will be operated by a nearly autonomous operating contractor on a two-shift 5-day week basis, our AEDC and ARO-Ames experience allows us to make an operating crew assessment. Unfortunately, proprietary interest will not allow the disclosure of this assessement herein, however, an unclassified summary can be given as Table 4. Note that the cost per "complete polar" for the three model support scenarios is also defined, and with some foresight into subsequent analysis these cost ratios will allow us to adjust the personnel complement to a normalized productivity base of 8000 "complete polars" per year.

TABLE 3

NTF HIGH ANGLE "COMPLETE POLARS" FROM "PARTIAL POLARS"
BY BENT STING MANIPULATION

GROUND RULES

SCENARIO

OVERALL: OPERATE AND MAN NTF FOR 8000 CRYOGENIC "PARTIAL POLARS" PER YEAR

NO. 1: 1500 CRYOGENIC "COMPLETE POLARS"/YEAR SHALL REQUIRE DOUBLE ENTRIES FOR THE 24-DEG RANGE MODEL SUPPORT SYSTEM (EFFECTIVE CRYOGENIC "COMPLETE POLAR" PRODUCTIVITY BECOMES 6500 "COMPLETE POLARS"/YEAR, 3000 "PARTIAL POLARS" ARE COMBINED TO GIVE 1500 "COMPLETE POLARS" AND THERE ARE 5000 "STRAIGHT-STING, PARTIAL POLARS")

NO. 2: 1000 CRYOGENIC "COMPLETE POLARS"/YEAR SHALL REQUIRE DOUBLE ENTRIES FOR THE 30-DEG RANGE MODEL SUPPORT SYSTEM (EFFECTIVE CRYOGENIC "COMPLETE POLAR" PRODUCTIVITY BECOMES 7000 "COMPLETE POLARS"/YEAR, 2000 "PARTIAL POLARS" ARE COMBINED TO GIVE 1000 "COMPLETE POLARS" AND THERE ARE 6000 "STRAIGHT-STING, PARTIAL POLARS")

NO. 3: 1000 CRYOGENIC "COMPLETE POLARS"/YEAR SHALL UTILIZE THE COMPLETE SPAN OF THE 41-DEG MODEL SUPPORT SYSTEM. (EFFECTIVE CRYOGENIC "COMPLETE POLAR" PRODUCTIVITY BECOMES 8000 "COMPLETE POLARS"/YEAR, 1000 " EXTRA POLARS" AND 7000 "PARTIAL POLARS" IN THE 24-DEG RANGE)

TABLE 4

NTF OPERATING PERSONNEL COSTS

(NEARLY AUTONOMOUS OPERATOR CONTRACTOR)

* NUMBER OF CONTRACTOR PERSONNEL: 75

* AVG. SALARY INCLUDING 30% FRINGE: $21,582/YR (1976)

* YEARLY PAYROLL WITH FRINGE COSTS: $1,618,650 (1976)

SCENARIO NO. 1, SAL/POLAR = $\dfrac{1,618,650}{6500}$ = $249.02

SCENARIO NO. 2, SAL/POLAR = $\dfrac{1,618,650}{7000}$ = $231.24

SCENARIO NO. 3, SAL/POLAR = $\dfrac{1,618,650}{8000}$ = $202.33

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* SKILLS MIX EVALUATED TO ARRIVE

  AT THIS NUMBER

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Direct Operating Cost for Table 3 Scenarios

As shown in the Table 3 scenarios, a year of productivity based on 8000 "partial polars" per year can be weighted to arrive at the cost per "complete polar" (C.P.) per year using the formulae:

$$\frac{\Sigma\ LN_2}{\Sigma\ C.P} = \left[P.P.\left(\frac{LN_2}{P.P}\right) + E.P.\left(\frac{LN_2}{E.P}\right)\right] \frac{1}{C.P./Yr.} \qquad (1)$$

$$\frac{\Sigma\ MWH}{\Sigma\ C.P.} = \left[P.P.\left(\frac{MWH}{P.P}\right) + E.P.\left(\frac{MWH}{E.P}\right)\right] \frac{1}{C.P./Yr.} \qquad (2)$$

These calculations are tabulated in Table 5. Note that for this 8000 "partial polar" per year productivity base, the overall cost is falsely represented as maximum for the 41-degree system.

Direct Operating Cost Normalized to 8000 "Complete Polars" Per Year

To correctly assess the payback for the two high angle model support systems as compared to the baseline configuration, the results calculated previously must be normalized to 8000 "complete polars" per year. To do this, we must diverge from the real world assumptions in the original scenarios (Table 3) and redefine some modified scenarios. That is, we must assume that the operating crews can work staggered shifts so that there is no quantum jump in personnel costs, and that the tunnel can be operated the required number of hours in a smooth way to get 8000 "complete polars"/yr productivity. This also implies that the required number of "partial" or "extra" polars must be allowed to vary proportionally to give the original mix as follows:

Scenario	High α "Extra Polars"	Straight Sting "Partial Polars"	Total All Polars
1A	1846.2	8000.0	9846.2
2A	1142.8	8000.0	9142.8
3A	1000.0	7000.0	8000.0

The resulting calculation of all factors of interest is shown in Table 6 and the results summarized in Figures 3 and 4.

The conclusions from this payback analysis are given in the body of this report.

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TABLE 5 – CALCULATION OF DIRECT OPERATING COST RATIOS FOR NTF WITH THREE MODEL SUPPORT SYSTEM SCENARIOS

(P.P. = "Partial Polar", E.P. = "Extra Partial Polar" for High Angle Data and
C.P. = "Complete Polar")

MODEL SUPPORT SCENARIO	St. Sting 24-Deg. P.P.	LN$_2$ Tons/P.P.	MWH / P.P.	High α E.P.	LN$_2$ Tons/ E.P.	MWH / E.P.	$\frac{\Sigma\,LN_2}{\Sigma\,C.P.}$ Tons/C.P.	$\frac{\Sigma\,MWH}{\Sigma\,C.P.}$ MWH/C.P.
No. 1 Baseline (6500 C.P./Yr.)	6,500	7.500	0.5600	1,500	7.500	0.56000	9.2308*	0.68923*
No. 2 30-Deg. Support (7000 C.P./Yr.)	7,000	7.500	0.5600	1,000	9.069	0.67464	8.79557	0.65638
No. 3 41-Deg. Support (8000 C.P./Yr.)	7,000	7.500	0.5600	1,000	11.946	0.88489	8.05575	0.60061

$$*\frac{\Sigma\,(X)}{\Sigma\,C.P.} = \left[\; P.P.\;(X/P.P.) + E.P.\;(X/E.P.)\;\right]/C.P.$$

CALCULATION OF DIRECT COST MERIT FACTORS FOR NTF WITH THREE MODEL SUPPORT SYSTEM
SCENARIOS (LN$_2$ @ $70/ton, Electrical Energy @ $25/MWH)

MODEL SUPPORT SCENARIO	LN$_2$ Tons/Yr.	Elect. MWH/Yr.	LN$_2$ 10^6 $/Yr.	Elect. 10^6 $/Yr.	Payroll $/C.P.	Payroll 10^6 $/Yr.	Total 10^6 $/Yr.	$/C.P.
No. 1 Baseline (6500 C.P./Yr.)	60,000	4480.0	4.2000	0.11200	249.02	1.61865	5.93065	912.4
No. 2 30-Deg. Support (7000 C.P./Yr.)	61,569	4594.7	4.3098	0.11487	231.24	1.61865	6.04332	863.3
No. 3 41-Deg. Support (8000 C.P./Yr.)	64,446	4804.9	4.5112	0.12012	202.33	1.61865	6.24997	781.2

TABLE 6 - CALCULATION OF AN APPROXIMATE PAYBACK NORMALIZED TO 8000 "COMPLETE POLARS"/YEAR

MODEL SUPPORT REDEFINED SCENARIO	$\frac{\Sigma LN_2}{\Sigma C.P.}$ Tons/C.P.	$\frac{\Sigma MWH}{\Sigma C.P.}$ MWH/C.P.	Payroll $/C.P.	LN2 Tons/Yr.	Elec. MWH/Yr.	People MY/Yr.	LN2 10^6$/Yr.	Elect 10^6$/Yr.	Payroll 10^6$/Yr.
No. 1A. Baseline (8000 C.P./Yr.)	9.2308	0.68923	249.02	73,846	5513.8	92.31	5.1692	0.13784	1.99216
No. 2A. 30-Deg Support (8000 C.P./Yr.)	8.79557	0.65638	231.24	70,364	5251.0	85.72	4.9255	0.13128	1.84992
No. 3A. 41-Deg Support (8000 C.P./Yr.)	8.05575	0.60061	202.33	64,446	4804.9	75.00	4.5112	0.12012	1.61865

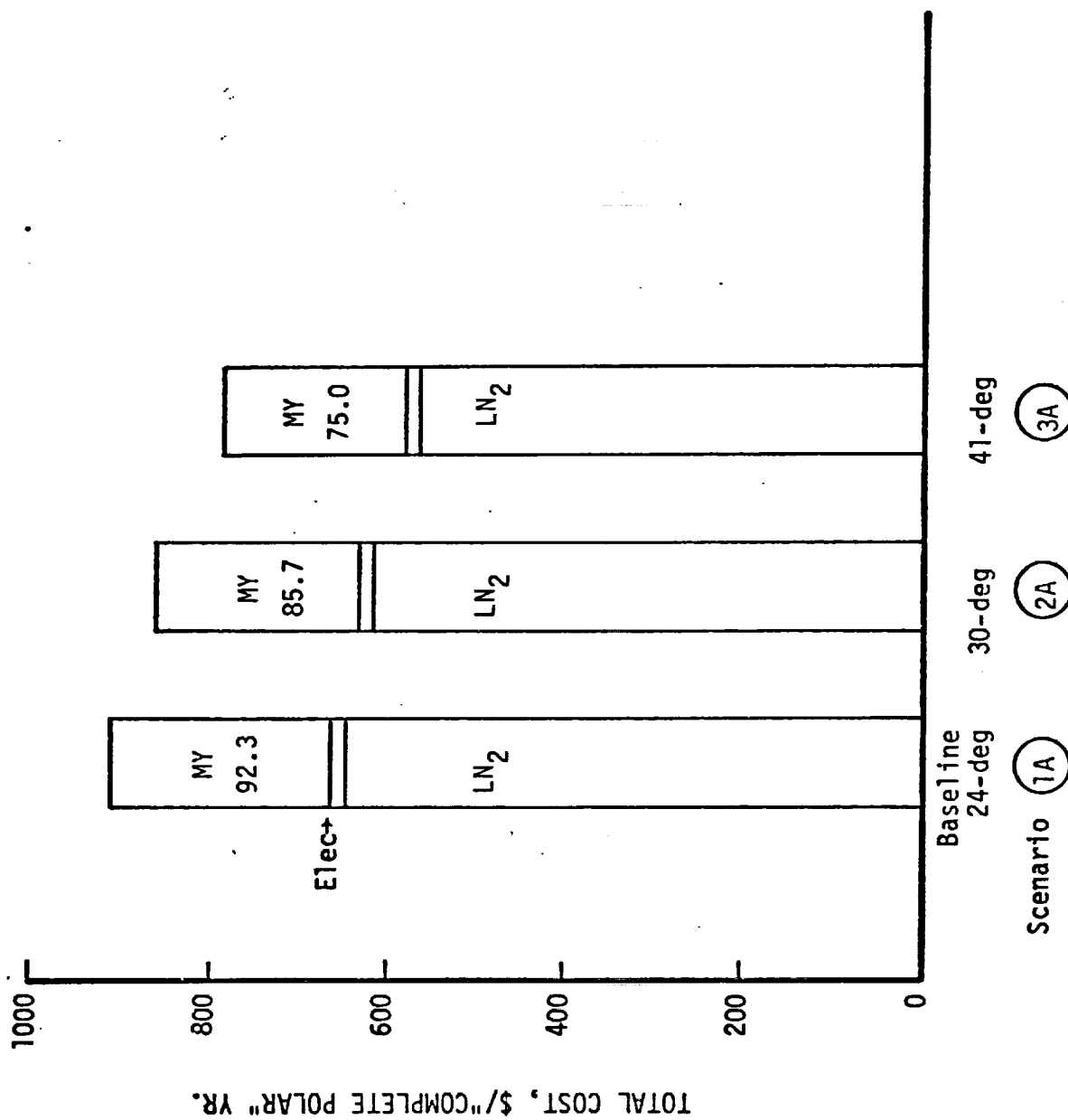|	Total 10^6$/Yr.	$\frac{\$}{C.P.}$	High α E.P.	St. Sting P.P.	Total All Polars	$\frac{\$}{A.P.}$	$\frac{\Delta}{10^6\$/Yr.}$	LN2 $/C.P.	Elec. $/C.P.
No. 1A.	7.2992	912.4	1846.2	8000.0	9846.2	741.3	1.04923	646.2	17.23
No. 2A.	6.9067	863.3	1142.8	8000.0	9142.8	755.4	0.65673	615.7	16.41
No. 3A.	6.24997	781.2	1000.0	7000.0	8000.0	781.2	0	563.9	15.02

FIGURE 3   "COMPLETE POLAR" COST BREAKDOWN FOR ONE-DEGREE PER SECOND
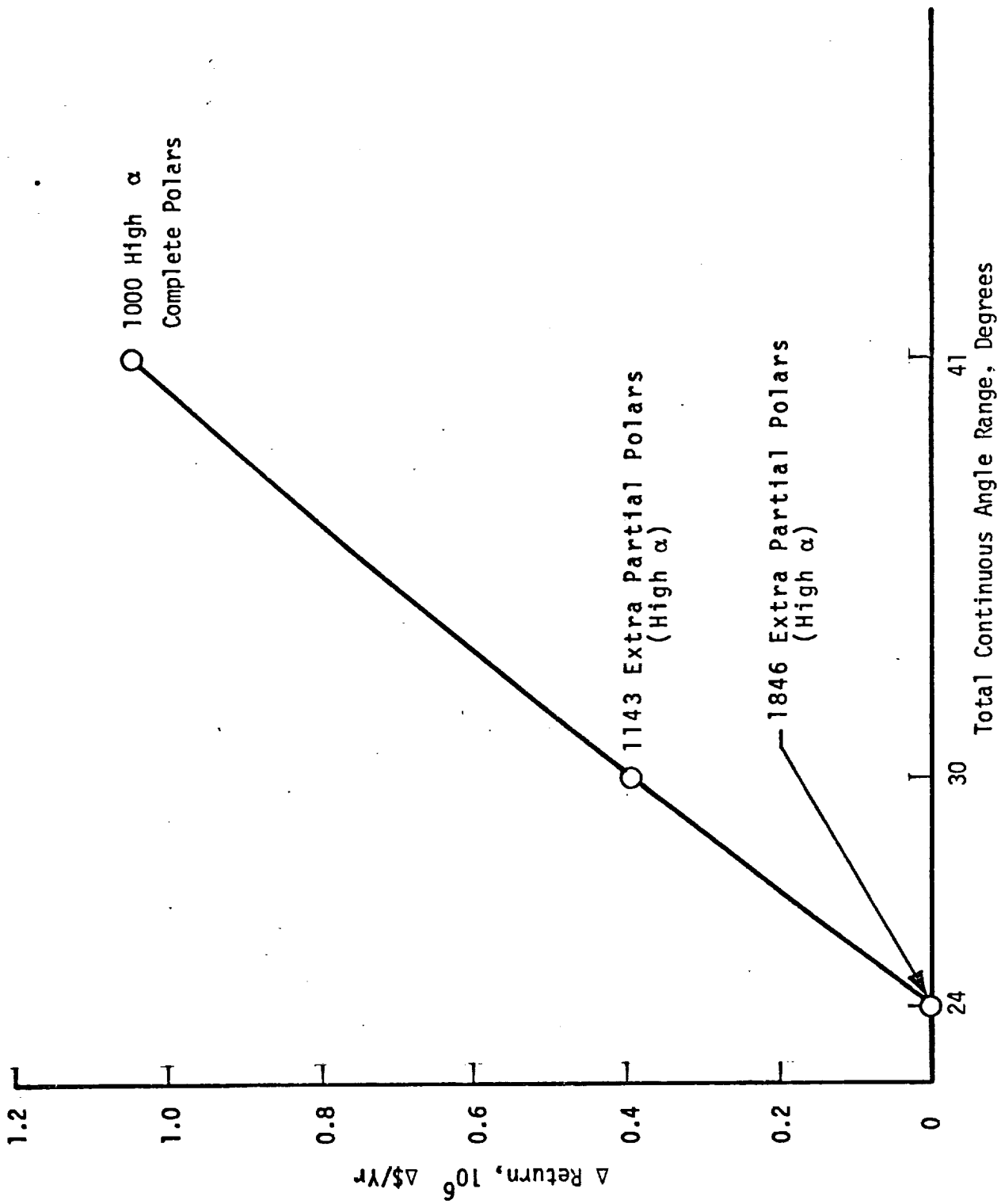CONTINUOUS SWEEP AND 8000 "COMPLETE POLARS"/YR.

Figure 4   Projected Annual Operating Cost Return Compared to the
24-Deg System for 8000 "Complete Polars"/Year

References

1. Davis, M. W., Gunn, J. A., and Dougherty, N. S., Jr., "Engineering/ Economy Studies of a National Transonic Facility Operated with Cryogenic Nitrogen," ARO, Inc., Engineering Report 75-9, July 1975.